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THE USE OF GAS IMAGING AS AN EMERGENCY RESPONSE TOOL

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The Use of Gas Imaging as an Emergency Response Tool*

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ABSTRACT

The Backscatter/Absorption Gas Imaging (BAGI) Technique is described and the results of the NAVSEA sponsored FY85 prototype design effort are reported. Applications of the technique are discussed.

INTRODUCTION

Over the past few years, there has been a considerable effort expended in the area of emergency response techniques in the case of the accidental release of a hazardous material. Many different organizations have produced an array of emergency response tools (NOAA-CHEMREPS, USCG-CHRIS, CMA-CHEMTREC) to assist the on-scene coordinator (OSC) in making timely and prudent decisions during the hectic period immediately following one of these accidents. These emergency procedures can be extremely involved and will vary in complexity according to the particular situation. However, in general, the OSC is faced with the task of addressing the following three main issues:

1) hazard identification
2) hazard mitigation or containment
3) evacuation.

This paper deals with the third of these three issues - evacuation, and describes the development of a new emergency response tool to aid the OSC in making the appropriate evacuation decisions.

Once it is determined that the potential of the accidental release warrants some evacuation procedures, the OSC is then faced with deciding the extent of the evacuation. In the past, the OSC has had little technical information to assist him in making these decisions. He would generally pick an evacuation radius based on a "best guess" of the magnitude of the release, and then order an evacuation of this area beginning with those people located in the apparent downwind direction. This attitude was one of "better safe than sorry", and often resulted in evacuation regions many times greater than actually required. These massive evacuations are very time-consuming and costly, and in some cases have resulted in more problems than the hazardous gas cloud.

A recent improvement has been the development of hazardous gas dispersion models capable of operating in essentially real time on personal computers or, in some cases, pocket calculators. However, these model and/or display packages still require as input accurate estimates of the hazardous gas source strength and the appropriate atmospheric conditions. They often do not handle local terrain effects on the cloud dispersion, or changes in wind direction, speed or stability which may occur during the course of the release. Furthermore, they generally do not include the effects of heavier-than-air vapor, aerosol formation or chemical reactions on the cloud dispersion. Knowledge of the actual size of the gas cloud and its direction of movement at all times is the type of information required for effective evacuation decisions. If the hazardous vapors were visible to the human eye, then airborne reconnaissance of the region of the release would provide the OSC with the necessary data to implement the proper evacuation plans. The Backscatter/Absorption Gas Imaging (BAGI) technique provides the ability to see gases at their dangerous concentrations through the integration of an infrared (IR) laser and an IR imaging system.

GAS IMAGING (WHAT IS IT AND HOW DOES IT WORK?)

The concept of the BAGI technique is to make gases which are not visible to the human eye visible on a standard TV monitor. The BAGI technique is inherently a qualitative, three-dimensional vapor detection scheme. Some possible system configurations are depicted in Fig. 1. In order to keep the system economical, operator-friendly, and field-reliable, the current system design does not provide quantitative concentration information. However, for many applications such as leak location or cloud tracking, the operator does not need to know the actual concentration of the gas. A system which will allow him to see the gas at concentrations of interest should be sufficient. For the applications shown in Fig. 1, it is the extent and direction of movement (upper scenario),

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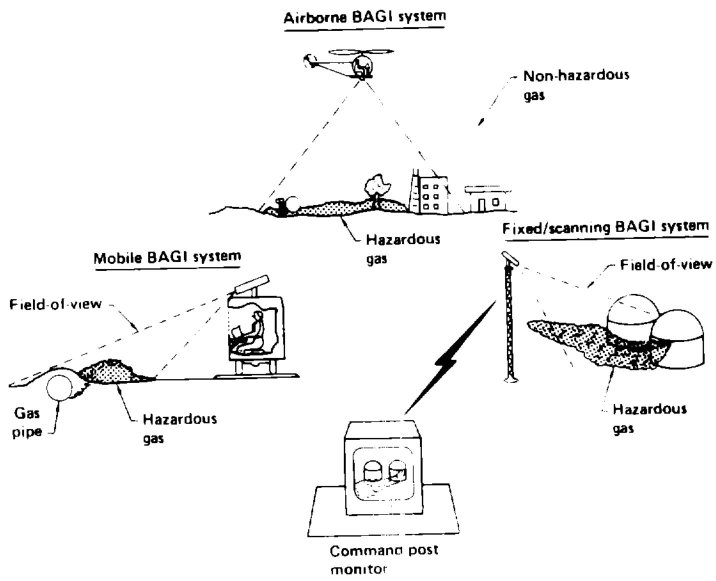

FIGURE 1. Possible BAGI System Configurations.

or location of the gas source (left and right scenarios) that is important--and the operator is provided with this information by simply watching the TV monitor. As will be discussed later, the technique does have some capability for gas-species selectivity; however, even if the system were to image another gas (upper scenario), the operator could still discriminate between the two gases because he can see the source and movement of each. Furthermore, since the information is in a standard TV format, it can be transmitted "live" to other locations for additional interpretation.

The principle of operation of the BAGI technique is the production of a video image by backscattered laser radiation, where the laser wavelength is strongly absorbed by the gas of interest, with the result that the normally invisible gas is now visible on the TV monitor. The technique has two basic constraints: 1) there must be a topographical background against which the gas is imaged, and 2) the system must operate in an atmospheric transmission window. The schematic of Fig. 2 shows the major components of a BAGI system--an IR TV camera, an infrared CO_2 laser and other ancillary components (electronics, TV monitor and transmitter and/or recorder). To date, only IR imaging systems have been considered since most hazardous gases are active absorbers in this spectral region. However, there is no reason why the technique would not work in visible and UV atmospheric transmission regions.

We will begin our discussion of gas imaging by first examining the physics of an ordinary passive IR image such as that shown in Fig. 3. This night-time image of the Army tank is produced by the thermal IR radiation emitted by the various topographical surfaces within the imager field-of-view. The contrast variations which form the image are a result of the spatial variations of the IR radiation from these surfaces. If we were to replace this thermal radiation with an equal amount of backscattered laser radiation, we would produce the same IR irradiance at the camera, and the same image of the tank would be produced. This process is depicted schematically in Fig. 4. At the left side of this example, the IR radiation from the surface within the imager field-of-view is replaced by an equal amount of backscattered laser radiation so as to form an image of the background. The background radiation is eliminated within the camera unit by inserting a narrow band pass filter in the optical path. Now let us introduce a gas into the field of view which strongly absorbs the laser radiation. In those regions where the gas is present, the backscattered laser radiation will be reduced as shown on the right side of Fig. 4. This produces a contrast difference in the image of the background (left side, Fig. 4) and the right side where the gas is present. The higher the gas concentration, the greater is the absorption, and the larger is the contrast. In this manner, the usually invisible gas becomes visible on the TV monitor, and its origin, size, and direction of movement are easily determined.

The likely results of a BAGI system can be demonstrated by examining a direct analogy to the IR gas imaging process--a visible gas imaging process. A black and white image of the vapor cloud produced by a nitrogen tetroxide leak is shown in Fig. 5.[1] The presence of the gas is clearly visible in this image. The analogy of this image with one which would be produced by the BAGI technique is as follows. The image of the terrain of Fig. 5 is produced by scattered solar

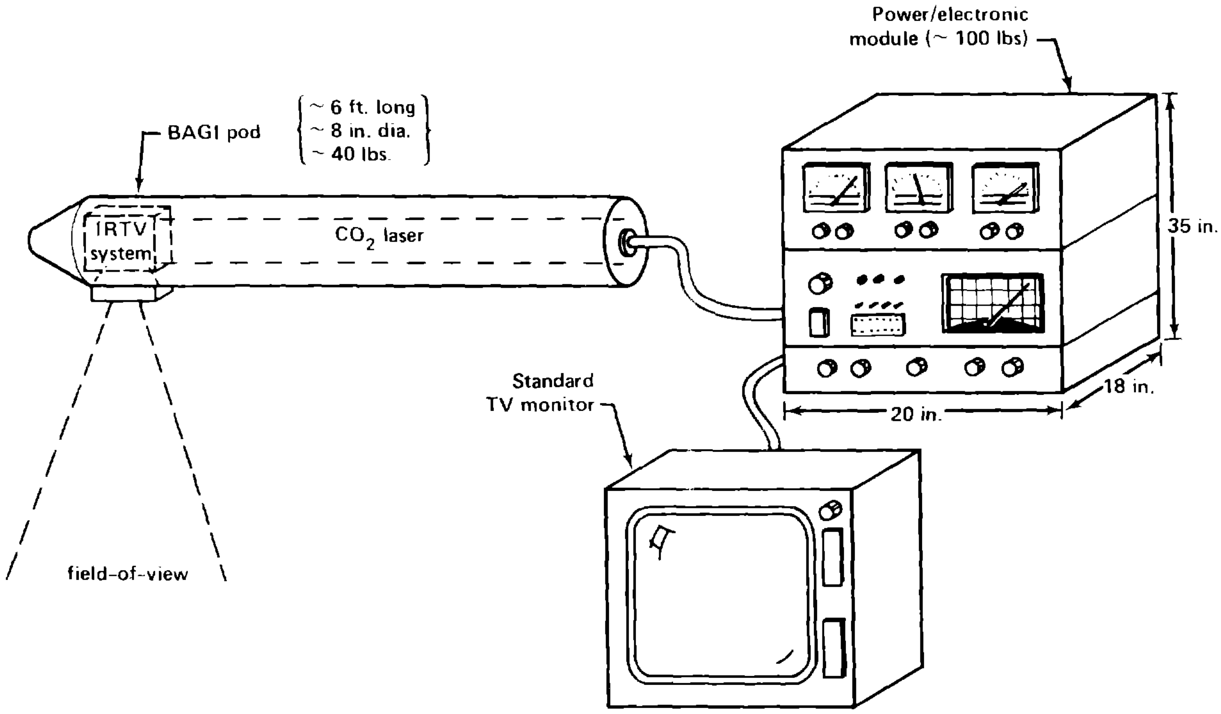

FIGURE 2. Schematic of BAGI System Components.

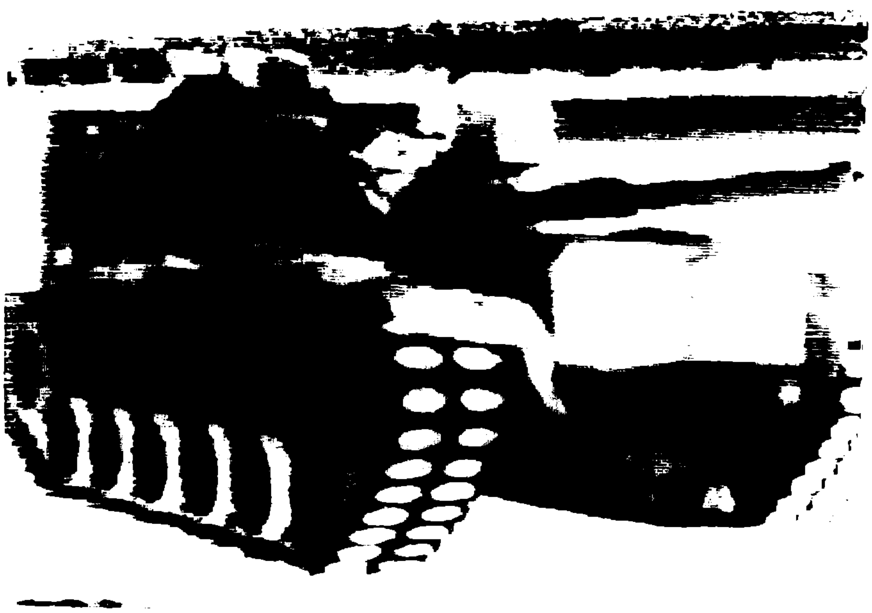

FIGURE 3. Passive IR image on an Army Tank (Courtesy of Inframetrics, Inc.).

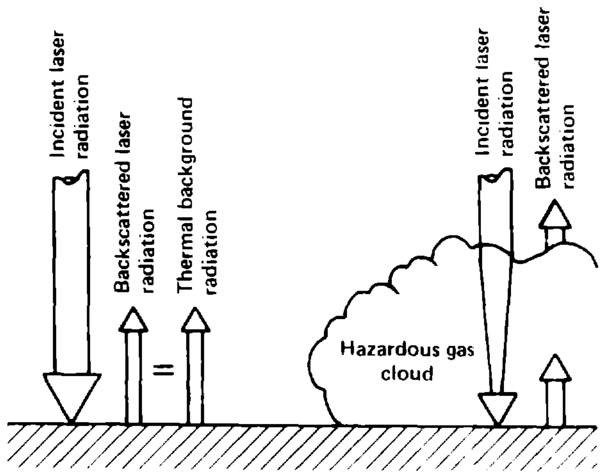

FIGURE 4. Schematic of Active Gas Imaging Process.

radiation; in the BAGI technique, it would be produced by backscattered laser radiation. The gas is visible in Fig. 5 because it strongly absorbs the scattered solar radiation; the same image will be produced with the BAGI technique if the backscattered laser radiation is strongly absorbed by the gas. So, Fig. 5 will be typical of a BAGI system image if the laser radiation is intense enough to adequately illuminate the terrain, and if it is strongly absorbed by the gas.

NAVSEA BAGI DEVELOPMENT PROGRAM

The development of a prototype BAGI system has been undertaken by the Naval Sea Systems Command (NAVSEA/OOC). The eventual use of the NAVSEA BAGI system is for the initial surveillance of disabled marine vessels for the presence of toxic or flammable vapors as depicted in Fig. 6. In these cases it is desirable to know if there is a leak on board, and, if so, where it originates. This information is crucial to the safety of the men who must board and secure the vessel. In Fig. 6, visual observation of the marine accident by the helicopter crew does not indicate any potential hazard for boarding. However, the BAGI image on the aircraft's TV screen clearly shows escaping vapors. With this information the vessels may be secured in a safe manner.

The first two phases of the program were completed in FY85 and involved studies of hazardous gas absorptivity properties and laser power requirements as they pertain to the desired maximum range of the system. The FY86 Phase III effort consists of the fabrication and both laboratory and field testing of a prototype BAGI system.

The Phase I portion of the program included both a literature search for existing hazardous gas CO_2 laser absorption coefficients and the construction of a system for measuring these coefficients for those gases which had not been previously reported. This effort has produced a database of absorption coefficients for the 60 strongest CO_2 laser transitions in the 9.2 - 10.9 μm spectral region. A list of the gases currently in the database is given in Table 1. Table 1 also includes an estimate of the BAGI system minimum detectable concentration and the threshold limit value-time weighted average (TLV-TWA) for each gas. These sensitivity estimates are calculated using the strongest CO_2 laser absorption coefficient in each case and assuming the gas cloud is 5 m thick. A more detailed description of these estimates is given in Ref. 2. Absorption coefficient measurements will continue throughout this coming year. We are hopeful that these data will provide a basis for species identification with a BAGI system.

The second aspect of the FY85 effort dealt with the BAGI system laser power requirements. In order to keep the system cost low and reliability high, only sealed tube CO_2 lasers were considered for the prototype BAGI system. In order to get a laser terrain irradiance equivalent to the thermal background radiance at the desired range of 1 km, a 20-25 watt laser operating at its natural beam divergence is required. This means the laser beam must be scanned in synchronization with the IR TV raster scan, a task which is much easier if one uses a "flying spot" type imaging system.[2] As part of the FY85 NAVSEA BAGI development project Inframetrics, Inc. performed a

FIGURE 5. Visible Analogy to IR Gas Imaging Technique.

study to determine the optimum modification to their IR TV system to allow reliable synchronization of the laser and the field-of-view of the scanning detector element. A modified Inframetrics model 600 IR TV system has been ordered for the prototype BAGI system to be constructed this year.

The goal of the FY86 effort will be the fabrication and evaluation of a long-range, multi-wavelength BAGI system. The system evaluation will include both laboratory and field trials. Current plans call for backscatter range evaluations in which the laser enhancement of the IR TV image will be recorded with the prototype BAGI system mounted atop a building at LLNL. An airborne evaluation of the system may be conducted if an available military helicopter can be located.

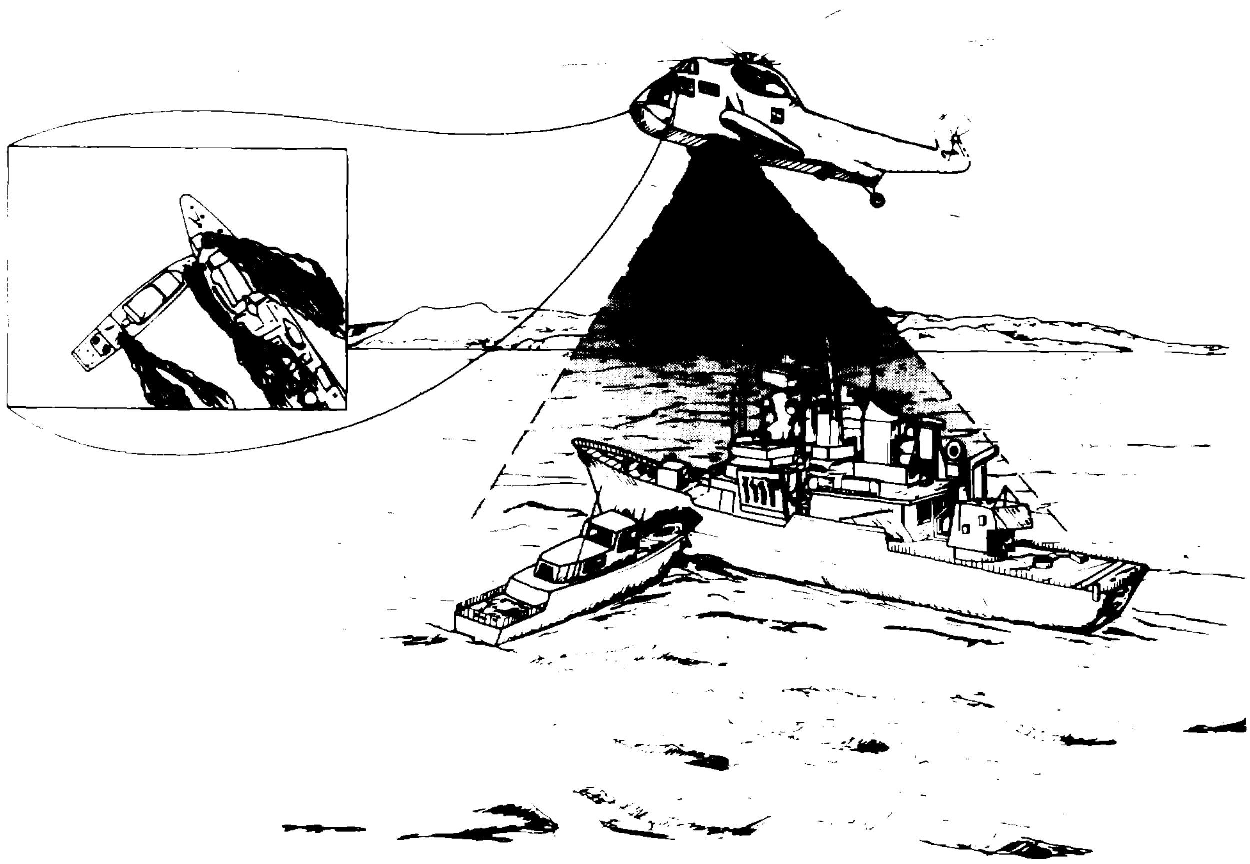

FIGURE 6. A BAGI System for Surveillance of Disabled Marine Vessels.

SUMMARY

The Backscatter/Absorption Gas Imaging (BAGI) technique is a promising new concept for the location and tracking of hazardous gases. The fundamental principle of the technique is that if hazardous gases were visible to the human eye, it would be easy to locate the source of a leak or, in the case of an accidental spill, to determine the extent and direction of movement of the resulting vapor cloud. The ability to image these gases thus represents a very practical emergency response tool. The BAGI technique offers a simple way to accomplish these goals by integrating an infrared (IR) laser and an IR imaging system. An airborne BAGI system could be used to determine the location of hazardous gas clouds resulting from disabled vessels at sea, train derailments or tanker truck accidents. This real-time capability would provide valuable input for evacuation decisions facing emergency response teams.

There appear to be many other applications of the BAGI technique be- sides the airborne surveillance of disabled marine vessels. A truck or van-mounted BAGI system could be used to survey natural gas distribution systems, to perform quick surveys of tanker trucks carrying hazardous materials, to locate leaks at industrial plants using or producing toxic or flammable materials, or to monitor the perimeter of hazardous-material dump sites during clean-up operations. The location of leaks of rocket or jet fuel at storage areas and during build-up, launch, and recovery would be a simple task for the van mounted BAGI system. An airborne system could even be used by the military as a defense measure in a chemical warfare situation by providing the commanding officer with the location and movement of the chemical agents.

TABLE I. CURRENT BAGI GAS ABSORPTION DATABASE AND DETECTION SENSITIVITY ESTIMATES

Gas	TLV-TWA (ppm)	Laser Wavelength (μm)	BAGI Sensitivity (ppm)
acetonitrile	40	9.29379	200
ammonia, NH_3	50	10.34928	2.5
benzene, C_6H_6	10	9.62122	41.5
butadiene, $CFCl_3$	1000	9.22953	2.4
t-butanol, $(CH_3)_3COH$	100	10.74112	21.6
chloroprene, C_4H_5Cl	25	10.67459	30.2
cyclohexane, C_6H_{12}	300	9.62122	200.2
1,2 dichloroethane, C_2H_4Cl	100	10.59104	160.3
dimethylamine, $(CH_3)_2NH$	10	9.75326	97.0
ethylacetate, $CH_3COOC_2H_5$	400	9.45805	6.7
ethylene, C_2H_4	5500	10.53209	2.9
ethylmercaptan, C_2H_5SH	0.5	10.19458	146.3
freon-12, CF_2Cl_2	1000	10.76406	1.7
freon-113, $C_2Cl_3F_3$	1000	9.60357	4.1
furan	?	10.18231	19.9
hydrazine, N_2H_4	0.1	10.44059	11.0
isopropanol, $(CH_3)_2CHOH$	400	10.49449	21.9
methanol, CH_3OH	200	9.67597	3.8
methylchloroform, CH_3CCl_3	350	9.24995	8.4
methylethylketone, $CH_3COC_2H_5$	200	10.59104	68.6
monochloroethane, C_2H_5Cl	?	10.27445	25.2
monomethylhydrazine, CH_3NNH_2	0.2	10.33370	24.0
orthodichlorobenzene, $C_6H_4Cl_2$	50	9.62122	10.8
ozone, O_3	0.1	9.50394	6.6
pentane, C_5H_{12}	600	9.67597	848
perchloroethylene, C_2Cl_4	100	10.74112	17.0
propane, C_3H_8	1000	10.81111	5.8
sulphur dioxide, SO_2	5	9.21969	758
toluene, $C_6H_5CH_3$	100	9.62122	124.4
trichloroethylene, C_2HCl_3	100	10.59104	6.6
trimethylamine, $(CH_3)_3N$	10	9.58623	20.1
unsymmetrical dimethylhydrazine, $(CH_3)_2NNH_2$	0.2	10.83524	21.1
vinyl chloride, C_2H_3Cl	5	10.61139	9.5
xylene, $C_6H_4(CH_3)_2$	100	9.53597	95.8

The BAGI technique shows promise as a long-range detection system capable of quickly locating the sources of hazardous gas and monitoring the dispersion clouds even at very low concentration levels. The system is simple to operate and interpret, and is composed of field-proven instruments which should make commercialization easy. For the specific tasks of remote detection of leaks in large complicated environments and the tracking of the resulting hazardous gas cloud, a BAGI system should make an excellent emergency response tool.

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